Orion Source I and its Outflow

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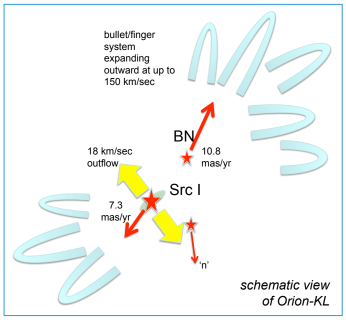


schematic view of Orion-KL

background

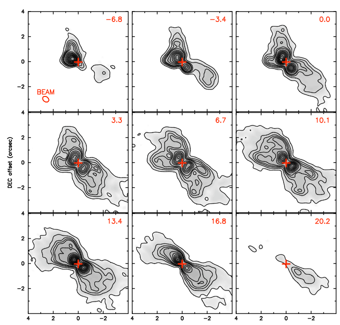
- Orion-KL is the nearest region of massive star formation (400 pc)
- the 2 most massive sources, BN and Source I, are recoiling from one another at ~40 km/sec
- projecting their proper motions backward, these 2 stars were within ~200 AU of one another just 500 years ago
- NIR images reveal a system of bow shocks suggestive of an explosive event 500-1000 years ago.

the current paradigm… (Rodriguez et al. 2005, Zapata et al. 2009, Bally et al. 2011)

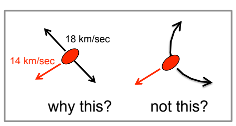
- BN and Source I were ejected from a multiple system 500 years ago
- the ejection of the stars unbound the surrounding gas/disks, creating the finger system

the '18 km/sec` outflow

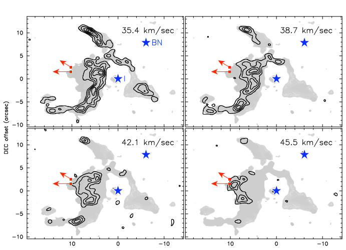
- Emerges along a NE-SW axis, perpendicular to the motion of source I
- presumably the true velocity is >> 18 km/sec, or the ambient gas is moving to the SE with Source I, otherwise the outflow would appear swept back to the NW



Channel maps of the 86.8 GHz J=2-1 SiO line mapped with CARMA, 0.45" resolution (Plambeck et al 2009). Red crosses mark the position of Source I. Bright spots near Source I are masers in the SiO ground vibrational state. 150 K contour interval..



Proper motion measurements (Gomez et al 2005) show that Source I is moving to the SE at 14 km/sec in the plane of the sky. If the bipolar outflow speed is 18 km/sec, why does it not appear swept back to the NW?



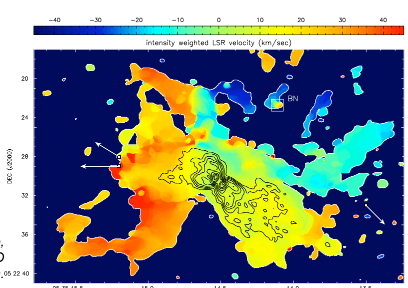
higher velocity gas

- Higher velocity gas, presumably part of the finger system, is seen farther from Source I – note the apparent acceleration away from the center

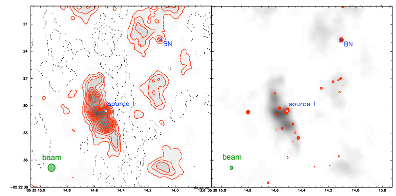
SiO channel maps (1" resolution) showing a velocity gradient in the redshifted high velocity gas. The contour interval is 12 K. Red arrows indicate the proper motions of HH objects 152-228 and 152-229 (Doi et al 2002).

two outflows… or one?

- The '18 km/sec' outflow appears to twist and merge smoothly with higher velocity, more filamentary gas
- Entrained by the explosive outflow, or evidence for precession?



Contours: SiO 5 km/sec channel map, 0.45" resolution. Color image: SiO velocity moment map, 1" resolution.



230 GHz continuum observations

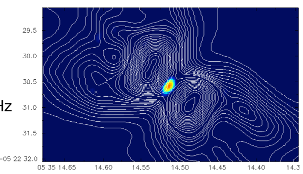
- Subarcsecond resolution is essential to measure the flux densities of Source I and BN

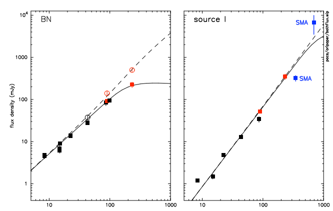
Comparison of 0.85" and 0.25" resolution continuum maps. Extended dust emission creates negative contours in the 0.85" map.

Source I is resolved

- Source I is slightly resolved at CARMA's highest resolution, 0.15"
- the deconvolved size, ~0.2" x 0.1" at PA 140°, is similar to that measured at 43 GHz (Reid et al. 2007, Goddi et al. 2011)

Halftone: 230 GHz continuum map; contours: the SiO 5 km/sec channel map.





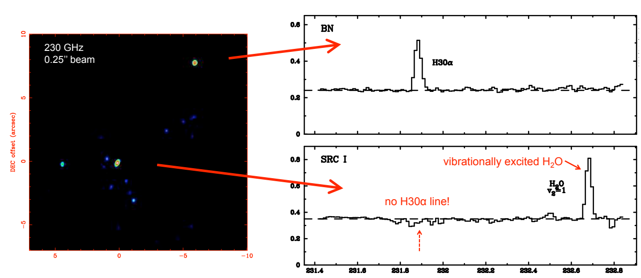
radio spectra of BN and I

- Consistent with free-free emission
- Turnover frequency ~200 GHz for BN, > 1 THz for Source I

CARMA flux densities – red squares for continuum (3mm: Friedel & Widicus Weaver 2011), open circles for recombination line + continuum.

continuum fits:

- Source I:
  - $S \sim \nu^2$, optically thick even at 230 GHz
  - model: r = 6.8 AU, $n_e = 3 \times 10^8$ cm^{-3}
- BN
  - $S \sim \nu^{1.3}$, indicates gradual falloff in electron density
  - H recombination lines detected
  - model: $n_e = 5 \times 10^7$ cm^{-3} inside $r_0 = 7$ AU, then decreasing as $(r/r_0)^{-3.5}$



spectral lines

- The H30α recombination line, prominent toward BN, is not detected toward Source I – consistent with optically thick free-free emission (... or a 1500 K radio photosphere)
- Vibrationally excited water prominent toward Source I
- Absorption by foreground vinyl cyanide, dimethyl ether, methanol toward Source I